Effect of Glove Liners on Sweat Rate, Comfort, and Psychomotor Task Performance[1]

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ABSTRACT

Military subjects participated in a study to evaluate four glove liners worn beneath chemical protective gloves, with regard to sweating of the hands, manual dexterity performance, and perceived comfort in a moderate thermal environment. Although there was a trend for subjects wearing the standard Army liner to experience the lowest sweat rate, the liner effect was not significant due to individual variation. No liner differences were found for manual dexterity performance, hand skin temperature, perceived temperature, and thermal comfort. Differences by liner were found for tactile descriptors used to assess liner comfort. Skin temperature, perceived temperature, and perceived thermal discomfort increased over the duration of the two-hour test, regardless of the liner worn.

Occupational skin diseases account for two-thirds of all job-related diseases, and seven out of ten industrial claims paid by insurance companies are for temporary disability resulting from dermatitis [11]. Chemicals are the most frequent cause of dermatitis [11]. Because a worker's hands are so vulnerable, industrial hygienists have relied on gloves as a preventive measure to limit dermal contact with hazardous materials. Yet gloves designed to provide chemical protection tend to be hot and to reduce dexterity.

The U.S. Army has found that hand sweating while wearing chemical protective gloves is a problem in terms of performance, comfort, and hand maceration. To alleviate the problem, light weight, stretchable, knitted, seam-stitched, cotton gloves are routinely worn under standard butyl rubber chemical/biological (CB) protective gloves to absorb moisture [4]. Because replacement of the current Army glove liner is under consideration, this study was designed to evaluate four selected glove liners worn beneath CB protective gloves with regard to their differential effects on hand sweating, manual dexterity performance, and perceived comfort in a moderate thermal environment.

The objectives of the research were to determine sweat rate and skin temperature of the nondominant hand; manual dexterity performance; perceived hand temperature, thermal comfort, and liner comfort; and moisture take-up of the test glove liners.

The following glove liners were selected for evaluation: the current standard 100% cotton, seam-stitched Army liner [14]; a 100% cotton seam-stitched liner adopted by the Air Force for use with the 7-mil and 14-mil CB gloves [1]; a 100% cotton string-knit candidate liner; and a 50% cotton/50% acrylic string-knit candidate liner. Physical characteristics of the glove liners are given in Table I. The two candidate liners were produced by a manufacturer to be as similar as possible while differing in fiber content. Each glove liner was worn beneath the 14-mil CB protective butyl rubber glove [13].

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TABLE I. Physical characteristics of glove liners.

	Army	Air Force	Candidate 1 cotton liner	Candidate 2 cotton/acrylic liner
Fiber content	100% cotton	100% cotton	100% cotton	50% cotton 50% acrylic
Weight, g/m²	135.6	206.9	352.7	325.5
Thickness, mm	0.02	0.04	0.06	0.06
Yarn count	18/1	35/1	14/1	14/1
Fabric structure	plain knit	rib knit	plain knit	plain knit
Wales per millimeter	711.2	914.4	381	381
Courses per millimeter	660	991	432	432
Length[a]	200.15	348.74	259.08	261.37

[a] Measured in millimeters from the tip of the middle finger to the lower edge when the gloves are flat and unstretched.

Methods and Procedure

EXPERIMENTAL DESIGN AND SAMPLE

A repeated measures Latin square design was used. Subjects were studied in pairs for the 32 sessions constituting the study. Sixteen sessions were conducted in the morning and again in the afternoon. All glove liners were tested an equal number of times in the morning and in the afternoon. Each subject participated in four 2-hour test sessions (two morning and two afternoon) while wearing each of the glove liners. Subjects were randomly assigned to a partner for each test session. All four glove liners were worn every test day. A sequence for wearing the liners was developed to counterbalance the potential carry-over effect of glove liner order.

Sixteen male military volunteers ranging in age from 18 to 25 years (mean = 21.1 years) participated as subjects. All subjects were enlisted Army personnel assigned on temporary duty to the Natick Test Subject Platoon at the U.S. Army Natick Research, Development and Engineering Center. All subjects were informed of the nature, duration, purpose, and benefits of the experiment, and each signed an informed consent statement. All subjects wore battle dress uniforms (BDUs) consisting of matching camouflage-patterned cotton/nylon twill shirt and trousers and laced mildew resistant leather combat boots. Since CB gloves are generally worn with chemical protective clothing, subjects wore a chemical protective jacket over their BDUs (see Figure 1). The coat consisted of a Quarpel® cotton and nylon twill outer shell and a laminated fabric lining.

TEST FACILITIES

Testing was conducted in the Sensory Analysis Psychophysiology Laboratory, Science and Advanced Technology Directorate, U.S. Army Natick Research, Development and Engineering Center. Ambient room temperatures ranged from 22.2°C to 29.7°C with a mean temperature of 26.1°C.

FIGURE 1. BDU and chemical protective jacket.

Skin temperature was measured with a YSI 709B thermistor attached with adhesive tape to the palmar surface of the nondominant hand. A General Eastern System 1100 dew point hygrometer was used to measure ambient room temperature and dew point of the hand from a sweat capsule attached to the skin with hypoallergenic skin glue. Skin temperature and dew point of the nondominant hand were continuously recorded on a Graphtec, Inc. P.O.C. Multicoder MC6624 strip recorder. A TRS-80 model III computer, which was interfaced with the strip recorder, recorded skin temperature, dew point, and sweat rate every five minutes. The conversion of dew point to sweat rate was calculated using Equation 1, as given by Brengelmann *et al.* [6]:

$$SR = \frac{M p\mathrm{H_2O} F}{ART} ,$$

where

SR = sweat rate,
M = molecular weight of water,
A = 1.13 cm^2 (area under the sweat capsule),
R = universal gas constant (62.358 mm Hg-liters/mole),
pH_2O = partial pressure of water in the sample gas leaving the capsule and was determined by dew point,
F = 3600 cm^3/s (flow rate), and
T = temperature in Kelvins of air entering the capsule.

Perception of hand temperature was assessed for each hand using the classic ASHRAE [3] seven-point rating scale, with one indicating cold and seven indicating hot. Thermal comfort was also assessed for each hand using a seven-point rating scale, with one indicating extremely comfortable and seven indicating extremely uncomfortable. The ballots were completed at fifteen-minute intervals throughout the experiment.

Assessment of clothing comfort is a complex subject since clothing comfort is related to physical, psychological, and physiological factors as well as to the interactions between these factors. There is general agreement that the movements of heat, moisture, and air through both fabrics and garments are major factors in clothing comfort. Most agree that discomfort is caused by liquid sweat remaining on the skin [7]. Hollies [9] concluded that "comfort acceptance of garments next to the skin is in some way related to the ability of these garments to remove sweat from the skin-garment interface." DeMartino *et al.* [7] noted that ideal clothing that touches the skin should be able to transport liquid water without feeling wet. In addition to the major factors affecting moisture transport, various tactile sensations are associated with clothing comfort. Terms that have been used in the past include clingy, scratchy, soft, heavy, light, and picky [7, 9, 10, 12].

For this study, we assessed the perception of wetness, fit, and tactile sensations associated with the liners using ballots (Figure 2) completed by the subjects at fifteen-minute intervals throughout the experiment. Definitions of the descriptors were provided to minimize the subjects' use of different definitions of the same descriptor. This instrument is an adaptation of those used by Hollies *et al.* [10] and Lofquist *et al.* [12]. A seven-point scale was also used to assess the subject's perception of the overall comfort of the liners, with one indicating extremely comfortable and seven indicating extremely uncomfortable.

For each of the words listed below, please write the number which best describes how you *perceive the feel* of the glove *liners* you are wearing today.

USE THE SCALE: 1 = Extremely, 2 = Mostly, 3 = Slightly, 4 = Not at all (according to the intensity of your feeling).

________	SNUG	(right or close in fit)
________	HEAVY	(in terms of weight of the liner)
________	STIFF	(resistant to bending)
________	STICKY	(moist and adheres to skin)
________	CLAMMY	(cold, moist, clinging to touch)
________	DAMP	(moistness or wetness)
________	ROUGH	(not smooth, coarse)
________	SCRATCHY	(irritating, itchy)

FIGURE 2. Liner comfort instrument.

A battery of tests was assembled as an index of manual dexterity performance, including the Purdue pegboard one-hand test, the Purdue pegboard assembly test, the Minnesota rate of manipulation one-hand turning and placing test, and the O'Connor finger dexterity test [15, 5, 8]. These tasks were administered, in the order indicated, at the beginning and again at the end of every test session.

Glove weights were taken, to the nearest 0.1 g, on a Sartorius electronic precision top-loading balance, model 1403MP7-2, both immediately before and after each test session.

TEST PROTOCOL

A glove-fit and manual dexterity training session was held before the test sessions. Each subject was fitted for a pair of appropriately sized 14-mil butyl CB protective gloves. The CB glove for each subject's nondominant hand was marked for the sweat capsule placement while the subject wore the glove. Five hand-dimension measurements, including hand, palm and thumb, crotch length, and hand breadth and circumference, were also made on the right hand of each subject while the subject was bare-handed. These measurements were subsequently used to choose each subject's standard Army liner to ensure the best fit possible. During the training sessions, the directions for each task were read and the procedure demonstrated by an investigator before the subject was given four test trials. Subjects completed two trials bare-handed and two trials while wearing their issued CB gloves with a nontest liner.

A hole 19 mm in diameter was subsequently cut for the sweat capsule in the CB glove for the nondominant hand. The liners were similarly cut after a bead of glue was applied around the marked opening to prevent raveling. The liners were conditioned at 20+/−2°C and 40+/−3% RH for 24 hours preceding the test session. Temperature and humidity conditions deviated from standard conditioning levels because a textile conditioning chamber was not available at the time of the experiment. Immediately before each test session, the liners and the CB gloves (and a paper towel) were sealed in individual plastic bags and weighed.

At the beginning of each test session, subjects donned, zipped, and snapped an appropriately sized chemical protective jacket over their BDUs. The liners were donned and evaluated for fit. The sweat capsule and skin temperature thermistor were affixed to the palmar surface of the nondominant hand (Figure 3). Once the CB gloves were donned and the sweat capsule secured, the two-hour test session began.

Subjects completed eight sets of temperature perception and thermal comfort ballots during the test. During the time between performing the two sets of psychomotor tasks, subjects were encouraged to participate in various nonphysical, mind-challenging games, such as Trivial Pursuit and Risk.

At the end of the test session, the probes were disconnected. The butyl gloves were removed and placed in their original plastic bag. The glove liners were removed and placed in their original plastic bag. The hand was wiped with paper toweling, which was then placed in the bag with the CB gloves. Both bags were sealed and weighed. The CB gloves were cleaned and prepared for the next day's testing.

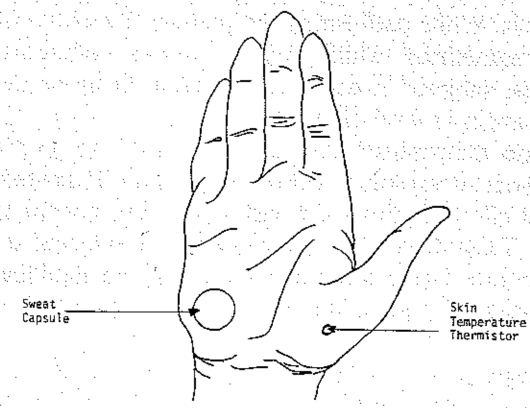

FIGURE 3. Placement of sweat capsule and skin temperature thermistor.

Results and Discussion

SWEAT RATE AND SKIN TEMPERATURE

Sweat rate for the subjects ranged from 0.52 to 0.65 mg/cm^2/min. Figure 4 presents the sweat rate data at 5-minute time intervals. There was a tendency for subjects to have the lowest sweat rate while wearing the standard Army 100% cotton liner and to experience the highest sweat rate while wearing the cotton/acrylic blend candidate liner, but an analysis of variance indicated that there were no significant differences between the glove liners. The sweat rate data showed considerable variation both between and within indi-

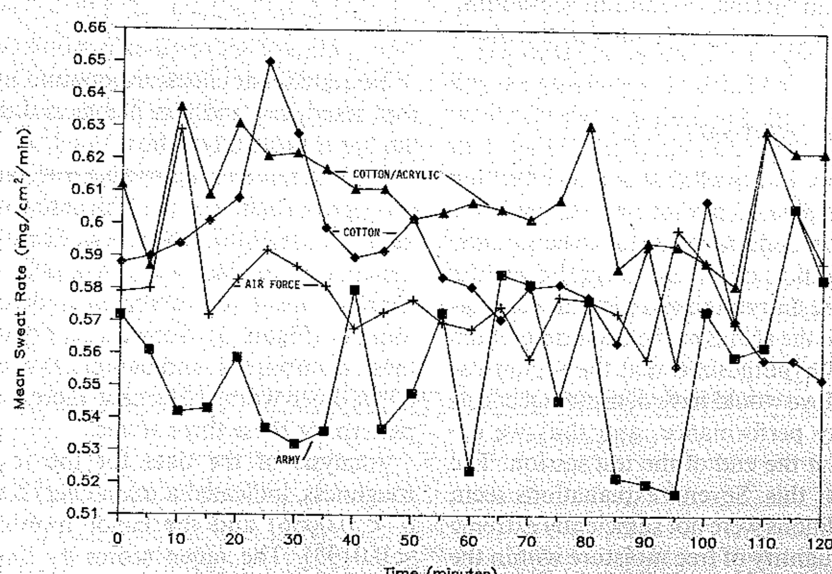

FIGURE 4. Mean sweat rate by glove liner over time.

viduals. While performing the manual dexterity tasks and sometimes while playing various competitive games, subjects' sweat rates increased, likely because of changes in level of arousal.

Skin temperature ranged from 35.4°C to 36.8°C. Analysis of variance of skin temperature indicated a main effect for time of measurement but not for the liner. Regardless of the glove liner worn, subjects' skin temperatures increased over time with no significant differences by glove liner.

Perceived Hand Temperature and Thermal Comfort

Mean perceived temperature of the instrumented hand ranged from 4.69 to 5.94 and 4.81 to 6.0 for the non-instrumented hand on the 7-point scale. ANOVA results for perceived hand temperature of the instrumented and the noninstrumented hand determined a main effect for time but not for glove liner condition. Thus, subjects rated both hands warmer over time regardless of the glove liner worn. Data on the perception of thermal comfort were similar to the temperature perception data, with subjects reporting greater thermal discomfort as time progressed for all liner conditions. Mean perceived thermal comfort of the instrumented hand ranged from 4.13 to 5.63 and 4.06 to 5.56 for the non-instrumented hand. A main effect for time was significant. No significant differences were found by hand (instrumented versus non-instrumented) for either perceived temperature or perceived thermal comfort. Thus subjects experienced a moderate sweat rate and skin temperature and reported moderately warm temperature and thermal discomfort sensations. The perceptual data were in agreement with the physiological responses.

Manual Dexterity Performance

Analysis of variance indicated that a main effect for time was found for three of the four tasks, the Minnesota, the O'Connor, and the Purdue one-hand tests. For these tasks, regardless of the glove liner worn, the scores obtained at the end of the test session were significantly better than the scores at the beginning of the test session. We had hypothesized that the accumulation of sweat in the glove would have detrimental effects on manual dexterity performance, and thus we expected lower scores at the end of the test session. The data did not support this. Several explanations seem plausible. First, conditions were not sufficiently extreme to produce a large quantity of free moisture within the gloves. Hand maceration was not found in any of the subjects. The limited moisture accumulation may have actually enhanced manual dexterity by making it easier to grip. Second, motivation may also have played a role. The second set of dexterity tasks was conducted at the end of the test session and the subjects may have exerted more effort knowing that they would soon be free. No glove liner effect was determined. Thus, psychomotor performance did not appear to be influenced by the type of liner worn beneath the protective glove under the moderate environmental conditions of this experiment.

Perceived Liner Comfort

For the first descriptor, snug, a liner effect was highly significant ($F = 7.8$, $p < 0.003$). Examination of these data, which are shown in Table II, indicates that the Air Force liner was the least snug and the standard Army liner was reported as being the most snug. Indeed, subjects frequently complained about the snug fitting Army liner. A main effect for liner was also found for the second comfort descriptor, heavy ($F = 5.07$, $p < 0.0041$, Table II). Both of the candidate liners were perceived by the subjects as being heavier than the standard Army and Air Force liners.

TABLE II. Mean liner comfort votes for snug and heavy descriptors by liner.

Liner comfort descriptor	Army liner	Air Force liner	Candidate 1 cotton liner	Candidate 2 cotton/acrylic liner
Snug	1.98	2.91	2.12	2.08
Heavy	3.61	3.61	3.37	3.27

No significant effects were found for the third comfort descriptor, stiffness. Subjects did not find any of the liners especially stiff.

A ballot number main effect was found for the fourth descriptor, stickiness, the fifth descriptor, clammy, and the sixth descriptor, dampness. Since a liner effect was not found, the data were collapsed over liners to determine mean scores for each descriptor by ballot number (Figure 5). Subjects reported increased stickiness, clamminess, and dampness over time regardless of the liner worn. Note that there was a very similar pattern for these three terms.

Analysis of the data for the seventh descriptor, roughness, indicated a main effect for liner ($F = 4.79$, $p < 0.0056$) and for ballot number ($F = 2.52$, $p < 0.0193$). The mean scores by liner over time are shown in Table III. Examination of these data indicates that the Air Force liner was perceived as the least rough.

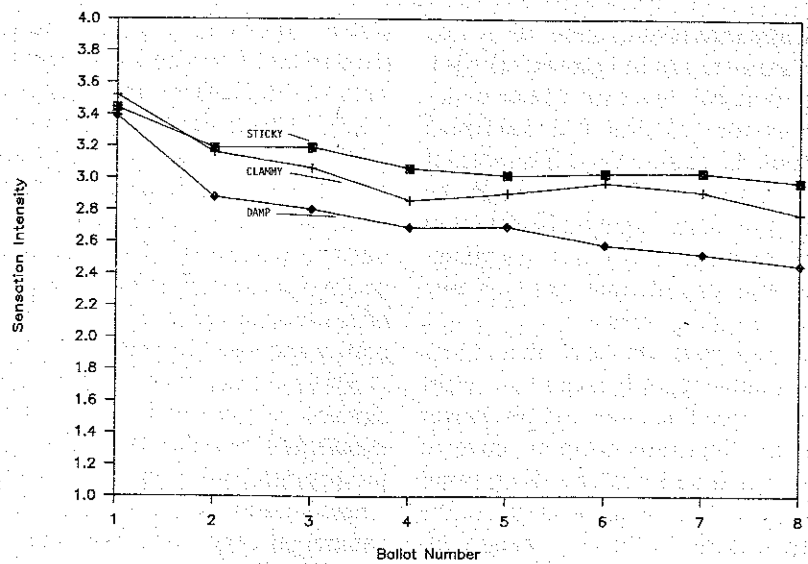

FIGURE 5. Mean wetness descriptors over time.

There was also a trend for the two candidate glove liners to be perceived as rougher than either the Army or the Air Force liners. While there were no significant main effects for the eighth descriptor, scratchiness, there was a tendency for the subjects to rate the two candidate liners as being more scratchy.

Mean overall liner comfort scores ranged from 4.1 to 5.6. Results of ANOVA showed that there was a main effect for ballot number but not for liner. Thus subjects reported increased liner discomfort over time regardless of the liner worn.

GLOVE WEIGHT CHANGES

To determine moisture take-up of the test glove liners, the liners were weighed immediately before and after each test session. Mean weight differences are given in Table IV. ANOVA results indicated a significant difference in liner weight changes. Post-hoc Sheffe comparison showed that the weight changes for the Army and the 100% cotton candidate liners were significantly less than the weight change of the Air Force liner. The weight change for the Army liner was also significantly less than the weight change for the cotton/acrylic candidate liner.

TABLE IV. Mean glove liner weight change (in grams).

	Army liner		Air Force liner		Candidate 1 cotton liner		Candidate 2 cotton/acrylic liner	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weight change	5.6	1.8	13.6	7.9	9.2	4.1	11.3	3.0

Examination of the sweat rate data (Figure 3) and the liner weight change data (Table IV) shows that while sweat rate did not differ significantly by liner or over time, significant weight changes were found by glove liner. While these data may appear contradictory, several explanations are possible. First, there was a slight trend for subjects to experience the lowest sweat rate while wearing the standard Army liner and the highest sweat rate with the cotton/acrylic candidate liner. While

TABLE III. Mean liner comfort scores for the descriptor roughness by ballot number.

Liner condition	Ballot number 1	2	3	4	5	6	7	8
Army liner	3.44	3.38	3.38	3.19	3.13	3.38	3.31	3.31
Air Force liner	3.75	3.63	3.50	3.56	3.69	3.63	3.63	3.63
Candidate 1 cotton liner	3.31	3.13	2.94	3.00	3.06	3.00	3.00	3.00
Candidate 2 cotton/acrylic liner	3.13	3.25	3.00	3.13	3.00	2.81	2.94	2.88

this was not statistically significant, these sweat rate data and weight change data are in agreement. Also, it would be valuable to repeat this experiment under more extreme environmental conditions to determine if a similar pattern could be detected and if significant differences could be found. Second, although the method of measuring sweat rate based on detection of dew point has many advantages, perhaps the microclimate beneath the sweat capsule may not be a true representative of the hand skin surface.

Finally, the characteristics of the glove liners (both design and fabric) undoubtedly influenced the weight change data. The Air Force liner was notably longer than the other three test liners and therefore covered a portion of the lower arm and was absorbing sweat from this part of the body also. Thus, the design of the glove was an important factor in the large weight differences observed. This glove also had the finest yarn and the tightest fabric structure. All of these factors contributed to the ability of the Air Force glove liner to hold moisture. The standard Army liner was the lightest weight, the least thick, and the shortest of the four liners. Thus, it is reasonable for this liner to take up and hold the least amount of moisture.

The two candidate liners had the same fabric structure, number of wales and courses per millimeter, yarn count, and glove design. They differed in fiber content and weight, with the 100% cotton candidate being heavier than the cotton/acrylic blend. Therefore differences observed between these two liners are likely due to fiber content.

Conclusion

This study was designed to determine the effects of four glove liners on sweating of hands, absorption of sweat by glove liners, manual dexterity, and perceived comfort in a moderate thermal environment. Although there was a tendency for subjects wearing the standard Army liner to experience the lowest sweat rate, and subjects wearing the cotton/acrylic candidate liner to experience the highest sweat rate, the glove liners studied did not produce statistically significant effects on either sweat rate or manual dexterity under conditions of this experiment. The dexterity measures used are sensitive and reliable. It is possible that no glove liner being considered for use with chemical protective ensembles will have a significant impact on manual dexterity because of the overriding effect of the butyl gloves.

Several comfort measures revealed significant differences between glove liners. The standard Army liners were perceived as most snug; indeed subjects frequently complained about the snug fitting Army liner. Both string-knit candidate liners were judged heavier than the standard Army and Air Force seam-stitched liners. The Air Force glove liner was also rated as the least rough. Second, for several descriptors, comfort changed as the experimental session progressed. Specifically, the glove liners felt significantly more sticky, clammy, and damp over time. These factors contributed to the significant increase in overall discomfort during the experimental session across glove liners. From a methodological perspective, it is interesting that the same pattern emerged for these three "wetness" descriptors.

These results show that significant differences in clothing comfort can be measured even when objective measures of variables related to comfort, such as skin temperature and sweat rate, do not reveal differences. These studies were conducted under moderate environmental conditions. We expect that future studies of this sort, under more extreme thermal conditions, will reveal significant differences in a wider spectrum of comfort measures, as well as sweat rate and behavioral performance.

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The views, opinions, and findings contained in this paper are our own and should not be construed as an official department of the Army position, policy, or decision, unless so designated by other official documentation.

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Spin Finishes for Cotton[1]

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ABSTRACT

Cotton has an exceptional natural finish, but under adverse conditions of weathering, this finish may deteriorate to the extent that processing quality is altered. Changing technologies involving higher processing speeds and new spinning systems have placed increased demands on the fiber properties of all cottons. Spin finishes could reasonably improve the processing qualities of both damaged cottons and cottons in general. The history of effective finish usage (additives) in both ginning and textile processing of cotton has been reviewed. Cottons harvested both before and after significant weathering in the Mississippi Delta, with and without added finishes, were evaluated for spinning quality. The cottons harvested before and after weathering had similar traditional fiber properties of length, strength, and micronaire, but the weathered cottons were poorer in grade, color, and trash. The processing performance of the unweathered cottons was superior to that of the weathered cottons. A hydrocarbon plus surfactant additive improved the processing performance of the weathered cottons in relation to processing waste and dust generation, but did not improve spinning end breakage or yarn strength.

Spin finishes or producer finishes are an integral, required component of most synthetic fibers. Without them, the fibers cannot be made into yarns on staple processing systems [12]. Under normal conditions, cotton has an exceptional natural finish, but under adverse growing conditions, especially wet weather at harvest time, the natural finish deteriorates because of the loss of ionic species and the loss or disruption of surface waxes. The resulting fibers have diminished

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